Renewable and Sustainable Energy Reviews 15 (2011) 4107–4117

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Current status of renewable energy in Nepal: Opportunities and challenges

Surendra K.C.[a], Samir Kumar Khanal[a,*], Prachand Shrestha[b], Buddhi Lamsal[c]

[a] Department of Molecular Biosciences and Bioengineering (MBBE), University of Hawai'i at Mānoa, 1955 East-West Road, Agricultural Science Building 218, Honolulu, HI 96822, United States
[b] Energy Biosciences Institute (EBI), University of California, Berkeley, Berkeley, CA 94720, United States
[c] Department of Food Science and Human Nutrition, Iowa State University, 2312 Food Sciences Building, Ames, IA 50011-1061, United States

ARTICLE INFO

Article history:
Received 28 December 2010
Accepted 5 July 2011
Available online 24 August 2011

Keywords:
Renewable energy
Fossil fuel
Hydropower
Developing country
Nepal

ABSTRACT

Energy is indispensible in modern society and is one of the most important components of socio-economic development. Nepal is one of the least developed countries with more than 80% of its population residing in rural communities. Per capita energy usage – often viewed as a key index of the development – in the country is far less than the global average per capita energy usage. The energy sector is dominated by the traditional energy sources such as fuel woods, crop residues and animal dung mainly for domestic usage contributing to about 86% of the national energy consumption. Currently 40% of the population has access to electricity, and the rural electrification accounts for only 29%. The majority of rural populations are meeting their energy needs by burning biomass in traditional stoves which has several environmental and public health issues. Nearly all fossil-derived fuels consumed in the country are imported in a refined form, and the perpetual increase in petroleum imports has adversely impacted the existing fragile economy of the country. Despite a huge potential in harnessing various renewable energy resources such as hydropower, solar power, wind energy and biofuels/bioenergy, these resources have not been sustainably captured due to geographical, technical, political and economical reasons. This paper presents a brief account of Nepal's renewable energy resources and the current status of various renewable energy technologies (RETs) such as micro-hydro, solar power, wind energy, biofuel/bioenergy, improved cook stoves, and improved water mill. It also highlights the opportunities and barriers for the development of RETs. Finally this paper presents some recommendations for the promotion, development and implementation of RETs in the country.

Contents

* Corresponding author. Tel.: +1 808 956 3812; fax: +1 808 956 3542.
E-mail address: khanal@hawaii.edu (S.K. Khanal).

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doi:10.1016/j.rser.2011.07.022

1. Background

Nepal is a mountainous landlocked country with an area of 147,181 km^2 (56,827 square miles). The country has a total population of 27.2 millions (2009 estimate) with an annual growth rate of 2.3%. Nepal remains one of the poorest countries in the world with a per capita income of $447 per annum [1]. About 80% of the nation's population lives in rural areas, and the country is characterized by small landholdings, rapid population growth, and a fragile economy (gross domestic product values only $12.5 billion US dollar [2]) resulting in chronic poverty in many regions.

Energy is indispensible in modern societies. We need energy for home appliances, lighting, transportation, cooking, heating/cooling, communication, and industrial processes to produce and supply commodities of our daily needs. Thus, energy is one of the most important indicators of socio-economic development, and per capita energy consumption is often viewed as a key index of the development. Developed countries have significantly higher per capita energy consumption. For example, the United States has a per capita energy consumption of 314.1 GJ/year, Japan has 162.5 GJ/year, and United Kingdom has 142.4 GJ/year. For Nepal, the per capita total primary energy supply (TPES) is just 14.2 GJ/year, which is far less than world's average per capita TPES of 76.6 GJ/year [3]. Nepal's total energy consumption in the fiscal year of 2008/09 was 400.5 million GJ. Traditional sources such as fuel wood, crop residues, and animal dung shared 87.1% of total energy consumption with commercial sources like petroleum products, coal and electricity, and other renewable sources contributing only 12.2%, and 0.7% of the total energy consumption, respectively [4]. Thus, Nepal's energy supply consistently depends on conventional energy sources such as fuel wood, crop residues, animal dung and fossil fuels. Though the rural sector accounts for 86.0% of the total energy demand of the country, this demand is primarily met by biomass sources such as fuel wood, crop residues, and animal dung.

Nearly all fossil-derived fuels consumed in the country are imported in a refined form from a neighboring country, India. Furthermore, there is a steady increase in the import of petroleum fuels over the years. For instance, the cost of petroleum fuel import was just around 27% of Nepal's total merchandise exports in the year 2000/01 which increased to nearly 53% in the year 2005/06. In 2005/06, the total cost of importing petroleum products was $35 million [5]. The growing dependency on imported petroleum fuels coupled with rising fuel price in the international market is severely impacting the already fragile economy of the country.

On the other hand, Nepal has economically exploitable hydropower potential of about 42,000 Megawatts (MW) [6]. However, only about 2% of this potential has been captured so far. Currently 40% of the population has access to electricity and the rural electrification accounts for only 29% [4]. Because of the high cost of grid connection, the average price of electricity is $0.096 per kWh [7]. This rate is among the highest in the region. Moreover, the share of electricity supplies from the reservoir-based hydropower plants (which contribute 13.3% of the total electricity generation) during peak demand is minimal, thereby resulting in a load-shedding of up to 16 h a day during the dry (winter) season [7]. The majority of Nepal's rural populations have been meeting their energy needs (mainly for cooking and heating) by burning various forms of biomass (forest wood, crop residues and dried animal dung) in open hearths or in traditional stoves. This practice is not only inefficient, but has also resulted in high incidents of respiratory diseases among the rural population, especially women and children, due to the high level of indoor air pollutants [8]. In addition, many people (mainly women and children) spend several hours per day in the drudgery of gathering firewood, often from considerable distances, to meet household needs. Because of these demands on their time and labor, women and children often have no opportunities for education and other productive activities. Therefore, such practices are neither sustainable nor desirable from economical, social, environmental and public health points of view.

Because of the country's increasing dependency on imported energy sources, and environmental and public health hazards associated with the traditional practices in the use of biomass as a source of energy, a decentralized, efficient, low cost and environment friendly energy supply system based on diverse indigenous renewable resources is the present need of scattered settlements in the country. Renewable energy resources are the energy resources that are obtained from sources that are replenished by nature. Some examples of renewable energy resources include moving water (hydroelectric power, tidal power, and wave power), thermal gradients in ocean water, biomass and biowastes (bioenergy and biofuels), geothermal energy, solar energy, and wind energy. Renewable energy resources (hydroelectric power, solar energy, biomass and biowastes) are sustainably available in Nepal (theoretical potential excluding solar energy, amounts to 1970 million GJ) and therefore, adequate utilization of these resources could certainly complement the country's renewable energy portfolio. Being environment friendly, renewable energy also contributes to significant reductions in greenhouse gas (GHG) emissions, local/indoor air pollution, and minimizes the impact on the landscape, and physical, geographical and natural environments [9]. Thus, a decentralized renewable energy system is likely to improve the life quality of the rural population in Nepal.

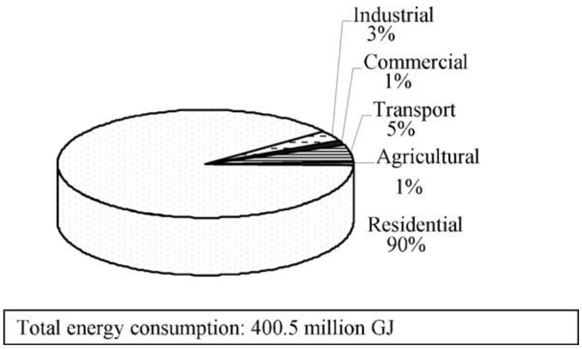

Fig. 1. Energy consumption by different sectors in the year 2008/09.

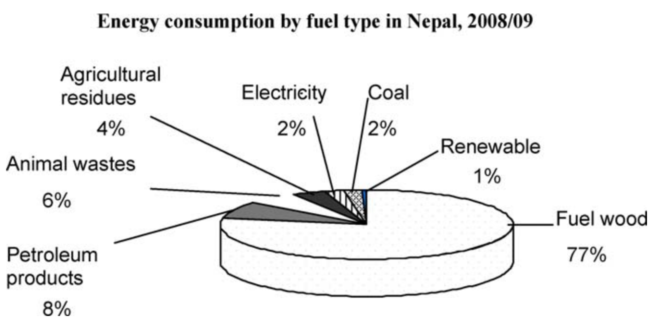

Fig. 2. Energy consumption by fuel type in 2008/09.

This paper highlights the current status of energy consumption by different sectors in Nepal and elucidates the role of renewable energy in contributing to the energy needs of rural areas. The paper further reviews the major renewable energy resources available in Nepal and their current status, and outlines the challenges and opportunities for promoting renewable energy technologies (RETs) in the country. The paper concludes with recommendations for development and adoption of renewable energy in Nepal.

2. Status of energy consumption in Nepal

In the fiscal year of 2008/09, 400.5 million GJ of energy was consumed by various sectors. Figs. 1 and 2 present the energy consumption by different sectors and by fuel types for the year 2008/09. The pattern of energy consumption by sector and the proportional share of different energy sources for the last 10 years are shown in Tables 1 and 2, respectively.

2.1. Residential sector

Energy consumption in residential sector, 356.8 million GJ in the year 2008/09, significantly contributes to the national energy demand [10]. The energy expenses are mainly for cooking, heating, animal feed preparation, and lighting. The rural population represents about 80% of the country's population and demands 85% of the residential energy. Yet the rural population has limited or no access, and lacks affordability to commercial fuels such as kerosene, liquid petroleum gas (LPG) and electricity [11]. Therefore, the energy dependence is primarily on biomass resources in these areas. Fuel wood alone supplies 86% of the total residential energy requirement followed by animal dung, agricultural residues and petroleum products. The overall growth rate of residential energy consumption is about 2.3% per annum [10].

2.2. Industrial sector

The energy consumption by the industrial sector was 13.4 million GJ, which is about 3.3% of total energy consumption in the year 2008/09. The main energy usages in the industrial sector are process heating, motive power, boilers, and lighting. Coal supplied 57.7% of total industrial energy demand, and electricity and biomass sources supplied 23.3% and 15.5% of the total demand, respectively. The industrial energy demand is increasing at 0.4% annually [10].

2.3. Commercial sector

Energy consumption in the commercial sector was 5.1 million GJ, accounting for about 1.3% of the total energy demand in the year 2008/09. Cooking is the largest end use in this sector consuming about 68.4% of the total energy consumption followed by lighting (19.3%), and space heating and cooling (5.3%). Petroleum, especially liquid petroleum gas (LPG) and kerosene, supplied about 53.0% of the total demand. Fuel wood and electricity fulfilled about 36.0% and 11.0% of commercial sector associated demand, respectively. The energy consumption in this sector has been increasing at an annual rate of 3.0% since 2001 [10].

2.4. Transportation sector

In terms of total energy consumption, transport sector is second to the residential sector. In 2008/09, the total energy demand of this sector was 20.9 million GJ which comprised 5.2% of the total energy consumed in that year. Road transport (86.5% of the total transportation sector associated energy consumption) dominates all other modes of transportation followed by the aviation sector (13.4%). Among fuels, high speed diesel (67%), motor spirit (20%), and air turbine fuel (12%) were the major fuel entities. For the last few years, the annual energy consumption growth rate in this sector has been about 8.9% [10].

2.5. Agricultural sector

The total energy consumption in the agricultural sector in the year 2008/09 was 3.6 million GJ, which accounted for 0.9% of total

Table 1
Annual energy consumption by various sectors in Nepal (unit in 1000 GJ) [10].

Sector	Years								
	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
Residential	301,142.9	314,615.8	320,180.1	326,248.0	331,520.5	337,627.5	345,384.3	351,191.9	356,752.1
Industrial	12,998.3	12,537.0	11,969.5	13,715.9	12,761.3	16,839.8	12,791.4	13,988.7	13,369.8
Commercial	4127.6	4921.3	5,228.1	5316.1	5335.0	5336.4	4673.8	4885.7	5122.2
Transport	13,591.5	12,024.6	12,702.8	13,132.0	13,894.2	13,469.5	14,509.5	15,036.6	20,876.0
Agricultural	3152.0	2776.2	2,888.0	2891.7	3084.7	2888.5	3010.6	2520.8	3646.4
[a]Other	408.5	454.4	484.0	533.3	611.6	624.1	680.3	758.4	739.9
Grand total	335,420.9	347,329.3	353,452.5	361,837.0	367,207.4	376,785.8	381,049.9	388,382.1	400,506.4

[a] Other sector refers to the energy used in public and religious sites such as street, temple, church, mosque, etc.

Table 2
Total energy contribution by various fuel types (unit in 1000 GJ) [10].

Category	Fuel type	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
Traditional	Agricultural residues	12,732.1	13,025.7	13,326.6	13,634.9	13,963.5	14,006.6	14,370.9	14,359.5	14,684.7
	Animal dung	19,491.8	19,901.1	20,319.0	20,745.7	21,181.4	21,626.2	22,080.3	22,544.0	23,017.4
	Fuel-wood	258,635.6	269,157.7	274,960.2	280,888.3	286,960.0	292,460.4	298,325.4	304,721.2	311,167.3
Traditional total		290,859.4	302,084.6	308,605.8	315,269.0	322,104.9	328,093.2	334,776.6	341,624.7	348,869.5
Commercial	Avian turbine fuel	2283.4	1716.3	1911.2	2316.4	2417.1	2327.0	2306.9	2493.5	2493.4
	Coal	7446.3	6481.0	5721.3	7292.4	6459.3	10,364.0	6158.4	8243.0	7751.5
	Electricity	4612.1	5065.8	5433.5	5974.5	6673.2	6969.9	7658.4	8100.8	8137.2
	Fuel oil	588.1	577.8	553.6	421.4	-27.7	1.2	52.8	27.2	0.0
	Gasoline	1984.1	2118.9	2259.1	2276.1	2533.6	2712.3	3413.0	3377.2	4158.4
	High speed diesel	12367.5	10856.8	11378.0	11368.7	11910.6	11163.9	11632.6	11481.6	17693.1
	Kerosene	11472.0	14017.8	12641.0	11270.6	8658.6	8217.9	7174.0	5628.1	2541.4
	Light diesel oil	133.7	94.4	23.9	23.1	3.4	11.4	7.0	12.0	14.8
	Liquid petroleum gas	1974.6	2400.8	2761.3	3256.8	3820.7	3988.7	4607.0	4768.3	5702.6
	Other petroleum	482.1	522.2	588.3	662.7	746.7	841.2	947.7	124.6	409.9
Commercial total		43,343.9	43,851.9	43,271.3	44,862.7	43,195.4	46,597.3	43,957.8	44,256.4	48,902.3
Renewable	Biogas	1179.2	1350.1	1526.5	1650.3	1847.5	2027.2	2222.1	2384.2	2593.1
	Micro-hydro	38.1	41.7	47.2	52.8	56.9	65.1	90.2	112.7	136.0
	Solar	0.3	0.9	1.7	2.2	2.7	2.9	3.1	4.1	5.6
Renewable total		1217.5	1392.8	1575.5	1705.3	1907.2	2095.2	2315.4	2501.0	2734.6
Grand total		335,420.9	347,329.3	353,452.5	361,837.0	367,207.4	376,785.8	381,049.9	388,382.1	400,506.4

national energy used in the same year. This energy demand did not include human and animal draft power (which is very difficult to assess). The major energy source is petroleum, contributing about 95.0% especially from diesel fuel, followed by electricity which shares 5.0% of the total demand. The consumption of electricity is, however, increasing at a higher rate than the petroleum [10].

3. Important renewable energy resources in Nepal

Energy resources in Nepal consist fuel wood, agricultural residues, animal waste, hydro-electric power, solar and potentially wind energy. The theoretical potential of known indigenous energy sources, excluding solar energy, amounts to 1970 million GJ annually indicating that Nepal has potential to meet and exceed all its energy needs [12].

3.1. Fuel wood

Forests cover 5.8 million ha (14.4 million acres, 22388 square miles) of land with total available biomass resources being 429 million dry metric tons [4]. Sustainable fuel wood supplies from forests were estimated to be just about 12.5 million dry metric tons for the year 2008/09, of which about 10.07 million dry metric tons is accessible due to rough terrain [10]. Forest biomass is a crucial resource for rural livelihoods in Nepal and 75% of energy is in the form of fuel wood, which is commonly harvested from forest [13–15] (Table 3).

Forest lands contribute to more than three-fourths of the total sustainable fuel wood production in the country. Furthermore, cultivated land, non-cultivated inclusion (NCI), shrub land, and grassland supply 9.3%, 5.5%, 4.5% and 0.4%, respectively, of the total sustainable fuel wood.

3.2. Agricultural residues

In rural areas with limited wood fuel supply, energy resources for cooking and heating are fulfilled by available field and processing co-products from different cereal crops (paddy, maize, wheat, and millets), oil seeds, grain legume, and fiber crop (e.g. jute). Agricultural residues are the third largest biomass source of energy after fuel wood and animal dung. The total potential availability of agricultural residues was estimated to be around 19.4 million dry tons for the year 2008/09 [10]. This amount is equivalent to a heating value of 243 million GJ that could contribute to about 61.0% of the total energy consumption in the same year. This estimation does not consider the fodder value of the agricultural residues as most of these residues are often used for feeding livestock. However, at least 50.0% of the agricultural residues can be considered for fuel purpose without affecting the other uses of these resources [10] (Tables 4 and 5).

3.3. Municipal solid wastes

Solid waste management is a serious problem in municipalities throughout the country, despite the fact that municipalities spend 20–25% of their total annual budget on solid waste management. The Asian Development Bank/International Centre for Integrated Mountain Development (ADB-ICIMOD) [16] reported that 58

Table 3
Annual biomass fuel production by different land types and regions (2008/09) [10]. Unit in 1000 dry metric ton (MT).

Land use type	Development region (RD)					Grand total
	Far-western	Mid-western	Western	Central	Eastern	
Cultivated land	131.3	197.4	251.6	269.8	315.7	1165.9
Non-cultivated inclusion (NCI)	78.0	122.8	158.0	164.9	164.9	688.6
Grassland	11.0	18.5	9.4	5.4	7.2	51.5
Forest	1619.6	2177.2	1306.7	2372.9	2561.2	10,037.6
Shrub land	95.0	116.2	63.3	92.7	195.9	563.1
Grand total	1934.9	2632.1	1789.0	2905.7	3245.0	12,506.6

Table 4
Production potential of agricultural residues by development and physiographic region (2008/09) [10]. Unit in 1000 tons.

Development region (DR)	Physiographic region			Grand total
	Hills	Mountains	Terai	
Central	357.5	1662.7	3939.7	5960.0
Eastern	361.7	1436.9	3179.2	4977.8
Far-Western	141.1	296.7	1073.4	1511.2
Mid-Western	109.1	952.1	1373.7	2434.9
Western	10.4	2448.1	2069.5	4528.1
Grand total	979.7	6796.6	11,635.5	19,411.8

Table 5
Energy production potential of agricultural residues by development and physiographic region (2008/09) [10]. Unit in 1000 GJ.

Development region (DR)	Physiographic region			Grand total
	Hills	Mountains	Terai	
Central	20,883.8	4490.1	49,483.1	74,857.0
Eastern	18,047.7	4542.9	39,930.3	62,520.8
Far-Western	3727.1	1771.6	13,481.7	18,980.4
Mid-Western	11,958.4	1369.8	17,253.6	30,581.8
Western	30,748.0	131.1	25,993.3	56,872.5
Grand total	85,365.0	12,305.5	146,142.0	243,812.5

municipalities in Nepal generate 1350 dry tons of solid wastes per day at the rate of 0.34 kg waste per capita per day. Although this rate of generation is less as compared to major Asian cities like Penang (0.98 kg/day-person), Taipei (0.95 kg/day-person), Singapore (0.94 kg/day-person), and Bangkok (0.88 kg/day-person) [17], solid waste management has become an important issue in Nepal. Five municipalities in Kathmandu valley, namely Kathmandu Metropolitan City (KMC), Lalitpur Sub-Metropolitan City (LSMC), Bhaktapur Municipality (BKM), Madhyapur Thimi Municipality (MKM), and Kirtipur Municipality (KRM), generate nearly 435 dry metric tons of solid waste per day, and 75% of the wastes originate from households. According to the Solid Waste Management and Resource Mobilization Centre (SWMRMC) [18], about 65.0% of the household wastes are reported to be biodegradable. The biodegradable organic fraction of municipal solid waste has a potential to generate renewable energy like biogas production via anaerobic digestion. The energy generation potential of solid waste is yet to be realized in Nepal (Fig. 3).

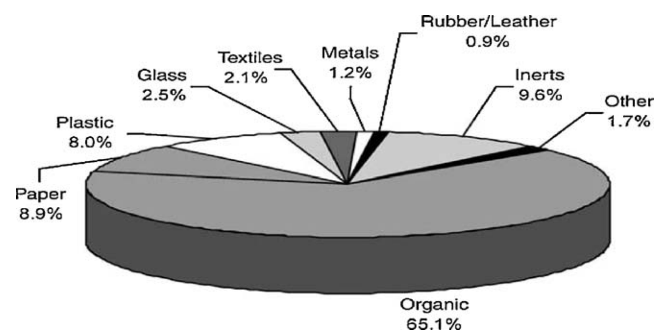

Fig. 3. Composition of household waste in Nepalese municipalities.

Besides the traditional forest- and agro-based industries such as saw mills, and rice and wheat mills, other industries also generate a significant amount of biodegradable organic wastes in different forms such as molasses and bagasse in sugar mills, and black liquor in paper mills. A detailed study on the cumulative solid waste generation by industry type is currently unavailable, but is required in assessing the energy production potential of industrial-derived wastes.

3.4. Hydropower

Nepal is rich in water resource possessing about 2.2% of the world's total water resources [19]. About 6000 rivers with total length of around 45,000 km and an annual discharge of 174 billion cubic meters are available in the nation [11]. The theoretical and commercial potentials of hydropower in Nepal are estimated to be about 83,000 MW and 42,000 MW, respectively (Table 6). In a span of about 100 km, Nepali rivers provide a potential height of about 4 km, thus providing a high linear energy density (33 MW/km) and large hydropower potential [6]. To date, Nepal has a total installed capacity of 689.3 MW which constitutes only about 2% of the total electrical energy potential. Hydropower plants alone have a total installed capacity of 635.9 MW, excluding the electricity generation from privately owned micro-hydropower plants. The remaining 53.4 MW is supplied by thermal (diesel) and solar photovoltaic power plants [7]. The hydropower station with a capacity up to 100 kW falls under a micro-hydel system in Nepal. It is estimated that about 50 MW of electricity can be generated by installing micro-hydel plants [10].

Table 6
Nepal's major river systems and their hydropower potential (figures are rounded) [6].

River basin	Potential in MW				
	Total theoretical potential	Technical potential		Economic potential	
		Number of project sites	Technical potential	Number of project sites	Economic potential
Sapta Koshi	22,350	53	11,400	40	10,860
Sapta Gandaki	20,650	18	6660	12	5270
Karnali and Mahakali	36,180	34	26,570	9	25,125
Southern River	4110	9	980	5	878
Total	83,290	114	45,610	66	42,133

Despite a huge potential for hydro-electricity, Nepal has not been able to fully harness its water resource for energy generation purpose. As a result, electricity is available to only 40% of the population, and rural electrification coverage is only about 29%. The rest of the population relies on traditional sources for their energy needs [4]. Electrification is very costly for a mountainous country like Nepal because of steep terrain and scattered settlements. The country lacks basic infrastructures like roads and transmission lines, and the cost of mega energy project like hydropower also demands significant investments. In addition, surmountable expenses to procure imported construction materials and equipments are associated with high transportation cost and inflation rate of Nepalese currency. Therefore, higher cost for electricity production is inevitable. Other factors responsible for poor hydroelectricity development in Nepal are: (i) lack of capital investment, (ii) lack of long-term planning due to political instability in the country, (iii) an inefficient bureaucracy, and (iv) lack of effective treaties among co-riparian countries for sharing the costs and benefit of large scale hydroelectricity projects.

3.5. Solar energy

On average Nepal has 6.8 sunshine hours per day with the intensity of solar insolation ranging from 3.9 to 5.1 kWh/m^2-day (the national average is about 4.7 kWh/m^2/day) [20]. Using photovoltaic (PV) modules of 12% efficiency and assuming peak sunshine of 4.5 h per day, the total energy generated would be 80,000 GWh/day or 2064 million tons of oil equivalent (Mtoe) per year. This energy would be nearly 17% of the world's total primary energy supply (TPES), which is estimated to be 12,267 Mtoe for the year 2008 [21]. If we use just 0.01% of the total area of Nepal, we can very generate solar electricity at 8 GWh/day; that is 2920 GWh/year, which is more than the energy generated from the Nepal Electricity Authority (NEA) owned power stations in the year 2008/09 (i.e. 1839.5 GWh) [7,22]. However, recently the Alternative Energy Promotion Centre's (AEPC) report on Solar and Wind Energy Resource Assessment in Nepal (SWERA) stated that the commercial potential of solar power for grid connection is only 2100 MW. Overall, the exploitation of this potentiality will largely depend on the acceptability and affordability of the technology.

3.6. Animal manure

Though livestock manure is often used as fertilizer in hilly and many parts of the plain (the Terai) region of the country, it is widely used as an energy source in the southern part of the Terai areas where forest resources are not easily available. Manure is used in both dried cake and gaseous form (biogas) commonly known as "*gobar gas*" for energy, and supplies 6.0% of the country's total annual energy demand. Dry cake is prepared by mixing animal manure with left over herbaceous biomass like cattleshed refuses and twigs. Animal dung is the second most common energy resource after fuel wood. Out of 14.9 million dry metric tons per year of cattle dung, about 12.2 million dry metric tons is available for utilization, and 15.0% of the available dung is used for energy generation by direct burning [10]. However, the energy content of dried dung cake, which is an energy source for the poor, is only about 11 GJ/metric ton (11 MJ/kg) [23]. Moreover, the direct utilization of animal dung for energy purposes has several environmental (higher CO_2 emission) and public health (indoor air pollution) issues. An alternative option is to use animal dung as a feedstock for biogas generation through anaerobic digestion. There is a growing use of biogas technology in Nepal with an annual increase of about 15.0% [10]. A greater discussion on anaerobic digestion is given in Sections 3.7 and 4.1.1.

3.7. Biogas technology

Livestock is an integral component of Nepalese farming system. The total households with cattle and buffalo in Nepal were estimated to be 1.2 million in 2001. Based upon the study, technical biogas potential of the country is estimated to be 1.0 million household level plants, out of which 57.0% in the Terai (plains), 37.0% in hills and rest 6.0% in remote hills or in mountain region [24].

3.8. Wind energy

As of now, wind energy is an unharnessed energy resource in Nepal. Due to its diverse topography and variation in meteorological conditions, it is difficult to generalize wind patterns in the country. The Solar and Wind Energy Resource Assessment (SWERA, 2002–2007) project reported a potential area of about 6074 sq. km with a wind power density greater than 300 W/m^2, and total commercial potential of 300 MW wind power considering the installed capacity of 5 MW per sq. km. However, most of the potential areas are very site specific in mountainous locations without infrastructure support.

3.9. Geothermal energy

There are 32 hot water spring sites that are situated in various parts of the country with water temperatures up to 50 °C [25]. They are currently being used for the therapeutic purposes. More study is needed to investigate the possible end uses of the hot water spring resources for geothermal energy generation.

4. Current status of various renewable energy technologies in Nepal

4.1. Biofuel/bioenergy

4.1.1. Biogas

Technology for biogas plant, commonly known as gobar gas by locals, has been available in all 75 administrative districts of the country. As of June 2009, some 2800 village development committees (VDCs) of the total 3913 in Nepal have biogas plants [24]. Table 7 shows the total number of biogas plants installed in the country. The installation of biogas plants of varying capacities (4, 6, 8, 10, 15 and 20 m^3, along with 300 institutional biogas plants) shows an increasing trend because of the technical and financial supports from the Biogas Support Program (BSP) of the Netherlands Development Organization-Nepal (SNV/N).

Presently, the Biogas Support Program (BSP) is the second largest to improved cook stoves (ICS) program for alternative rural energy program in Nepal. BSP also became the first Clean Development Mechanism (CDM) project of Nepal with the registration of 2 projects in 2005. However, biogas technology is not the panacea for the energy problem of rural Nepal because of several factors. Because the optimum temperature required for biogas production through anaerobic digestion is 35–37 °C, cold mountainous regions coupled with chilly winter throughout the country make it unfavorable for biogas production year round. There are still 10,375 households living above an altitude of 3000 m from mean sea level,

Table 7
Total number of biogas plants installed till mid July, 2009 [24].

Program	No. of plants
Biogas support program (BSP)	204,490
Gobargas support program (GSP)	4111
Prior to BSP and GSP	11,835
Total	220,436

Table 8
Target and progress of biomass program [30].

S.N.	Biomass program	Progress till March 2010	Target
1.	Improved cook stoves (mud)	359,155	434,000
2.	Institutional improved cook stoves	975	5000
3.	Iron cook stoves	1800	50,000
4.	Household gasifier	–	10,000
5.	Institutional gasifier	1	1000

and heating energy is crucial in those cold areas. Lack of adequate water for operating the biogas plants in hills and mountainous areas is another hindrance [26,27]. The availability of sufficient feedstock for biogas digesters is a critical problem for Nepal. Nearly all existing biogas plants, except institutional biogas plants, are operated on cattle dung. Thus, households need to have sufficient numbers of livestock in order to feed the digester with required manure for biogas production. Though installation of biogas plants are subsidized, depending on the plant size and remoteness, the cost share by individual household ranges from $143 to $357, which is still expensive for the rural populations [28]. Furthermore, the poorest of the poor who have no livestock, are unlikely to benefit from the subsidy policy of BSP. Lack of technical knowledge coupled with cold climates, are hindrances in increasing service coverage in poor rural areas. The main problem with a family-sized plant is low biogas yield during the winter and rainy seasons where as the problems for community-sized plants relate to ineffective management, and sharing of benefits.

4.1.2. Biomass technology

With more than 80% of the population relying on solid biomass fuel, such as wood, dung and agricultural residues for cooking and heating, the lower efficiency usage of these fuels and indoor air pollution (IAP) are the major problem in Nepal. The World Health Organization (WHO) estimates that 2.7% of Nepal's burden on disease is attributed to solid fuel use, which is resulting in nearly 7500 deaths per year [29]. To address the issue of IAP, improved cook stoves (ICS) have been identified as one of the most simple and cost-effective technologies in rural homes. The Biomass Program under the Alternative Energy Promotion Centre (AEPC) has been successful in installing ICS in the mid hills through collaboration with local non-governmental organizations (NGOs) and governmental organizations (GOs), without direct subsidy to households. The target and achievement of the program is elucidated in Table 8.

As the efficiency of traditional cooking stoves is only 3.0–15.0%, theoretically it is possible to reduce 50% of the 11 million dry tons of fuel wood annually used for cooking purposes by implementing ICS [31]. The actual amount of fuel wood saved, however, depends on other factors such as types of ICS, effective cooking practice, the condition of the fuel wood, the type and amount of food prepared, and the type of pots used for cooking. Even with a low performance of 11.0% fuel wood savings, estimates indicate that one ICS can save an average of 1 metric ton of fuel wood annually [31].

In spite of being a low-cost technology, existing models of ICS are incompatible with the traditional life-style. The openings in the currently designed ICS are too small to accommodate the large cooking utensils used in many households in Nepal. Similarly, in the diverse cultural settings of Nepal, people have different food preparation habits. Consequently, ICS models do not meet all the local requirements. Most importantly, ICS do not provide both cooking and space heating, which is especially important in the higher hills and mountainous regions. Moreover, ICS designed for fuel wood cannot handle agricultural biomass and industrial residues.

4.1.3. Bio-briquetting

Bio-briquetting process involves densification, through the application of temperature and pressure, of lighter and high moisture bulk materials such as crop and forest residues into a nearly dry, high density, and higher energy material known as bio-briquettes. They have better physical–chemical and combustion properties such as a higher heating value, and lower emission of undesirable gaseous pollutants such as SO_2 and NO_x [32].

Currently, private organizations and communities are producing briquettes from rice husk, weeds, household and agricultural wastes/residues. Because of limited research and development, the details of bio-briquette production and its contribution to national energy supply is currently unavailable.

Nepal produces enormous amount of crop and forest residues, and municipal and industrial organic solid wastes. Thus, biomass-derived briquettes could be good substitutes to wood, kerosene, coal and LPG at the household level for cooking, and boiler and brick kiln fuels at the industrial level. Bio-briquetting is a low-cost simple technology that is free from geographical and climatic limitations. Moreover, bio-briquette is ideal for both cooking and space heating, and has potential in reducing IAP by up to 90% [33]. The production of bio-briquette during monsoon season is, however, affected by proper storage and drying requirements. Other limitations of bio-briquette are its low volatility and long ignition time compared to fire wood. Moreover, bio-briquette is unsuitable to use in the traditional stoves.

4.1.4. Biofuel

The concept of biofuel is relatively new to Nepal. The Government of Nepal (GoN) announced its Biofuel Program in the fiscal year of 2008/2009 to promote biofuel in Nepal through AEPC. The program focuses particularly on *Jatropha curcas* L. as a biofuel feedstock for biodiesel production. The program has established 20 modern *Jatropha* nurseries through 12 different organizations, and has produced and distributed 1.25 million *Jatropha* saplings to interested farmers and organizations. Also, two processing plants – each with capacity of 1000 l biodiesel per day – have been established through two private organizations [34].

Several private companies have started commercial cultivation of *Jatropha* plants and have established a *Jatropha* research centre. According to Bhattarai [35], biodiesel can replace up to 5.0% of imported diesel within 2–3 years in Nepal. However, a detailed economic and technical feasibility study for *Jatropha*-biodiesel production needs to be conducted in the context of Nepal. For a country with limited accessible and arable land, large-scale cultivation of *Jatropha* could compete with food/feed production. Although, *Jatropha* can be grown in rather marginal and unarable land, the yield could be much lower. *Jatropha* grows with minimal input of water and survives through periods of drought, but the oil yield is dependent on water supply; some 20,000 l of water for each liter of biodiesel are thought to be required for *Jatropha* compared to 14,000 l for rapeseed and soybean [36].

The major challenge facing Nepal is growing food deficits, resulting in food insecurity at alarming levels [37]. More than half of the nation's 75 districts have been facing moderate to acute food shortages, and the government continues to airlift grain to remote areas [38]. It is very unlikely that large scale mono-cultures of energy crops, similar to those implemented in neighboring countries, could be appropriate for Nepal. Nepal however, is rich in its natural flora, so there can be several species of plants with promising values for producing biofuels. A study from 1980s showed that some 286 species of oil-bearing indigenous varieties of plants (edible and non-edible) were found in the country [39]. The non-edible varieties could be used for biodiesel production. Identification and sustainable utilization of such plant species would become an important step in establishing biobased industries in the nation.

Shrestha [40] reported that up to 12.0% (18,000 km^2) of the barren and under-utilized land could support cultivation of potential feedstock for biofuel production. Since community forestry in Nepal is one of the most successful programs in the nation, the incorporation of such potential feedstock in community forestry and their sustainable management could not only generate additional income for the community members; but also play an important role in contributing to national economy by curtailing the import of costly fossil fuels.

4.2. Micro and pico-hydro technology

Hydropower station with capacity up to 5 kW is grouped under pico-hydro system in Nepal. As of 2008/09, there are about 1977 micro-hydro (including pico-hydro) electrification schemes installed in various part of the country with total installed capacity of about 13.9 MW. There are about 6253 units for mechanical power generation for milling purposes [10]. The installation of micro-hydro plants increased significantly due to the subsidy policy implemented by AEPC/Energy Sector Assistance Program (ESAP) after year 2000. Realizing the huge hydropower potential, many renewable energy development programs have focused on the development of micro-hydro plants. Though 50 MW of electricity is estimated to be generated by micro-hydro, it costs around $2860 per kW of electricity which is higher than the capital cost of per kW electricity generation from larger hydropower plants [41]. Also, small hydro turbines need specific topographical conditions that are only found near a small percentage of users' dwellings. Similarly, most of the rivers are seasonal and during winter, the discharge is very low, causing higher fluctuation in electricity generation.

4.3. Improved water mill (IWM)

There are altogether 25,000 traditional water mills in the country. With the objective of improving the living condition of traditional water mill owner, IWM Program was started in the year 2003 under AEPC with the support of Government of Nepal and SNV/Nepal. By the end of November 2009, the program helped to install 5400 IWMs that provided efficient services to about 1,680,000 rural people in 280,000 households [41]. As IWM costs about $2143 per kW of hydro-electricity [41], the cost of installation is high for those rural water mill owners even though the cost per kW production of electricity is less than that of micro-hydro plants.

4.4. Solar

4.4.1. Solar photovoltaic (PV) technology

Solar PV systems are gaining popularity in some parts of Nepal. This is because the majority of the populations in rural areas have limited access to electrical energy, the cost of a diesel generator is high, biogas plants are not feasible in cold high altitudes, and small hydro turbines require specific topographical conditions which are not possible in many places. The estimated market potential is huge and about 8278.8 kW peak of photovoltaic power is currently being used in various public and private sectors in Nepal [42]. The total number and installed capacity of solar PV is shown in Table 9.

Table 9
Total number of systems and total installed capacity [42].

S.N.	Photovoltaic (PV) system	Installed capacity (Watt peak)	Number of system
1	Solar home system (SHS)	5,624,475	206,152
2	Small solar home system (SSHS)	737,258	155,574
3	Solar photovoltaic in communication sector	1,243,894	943
4	Institutional solar photovoltaic system (ISPS)	537,216	415
5	Solar photovoltaic pumping system (PVPS)	135,969	76
	Total	8,278,812	363,160

This technology however, requires higher initial investment as it costs about $14,286 per kW of electricity generation depending upon the capacity, which the rural population may not be able to afford [41]. Also, NEA has carried out centralized solar photovoltaic-based rural electrification in different locations. The cost of a centralized solar PV-based power system is higher compared to electricity generation by smaller micro-hydropower units. Furthermore, solar PV is weather dependent and fails to provide consistent energy supply to households. This technology is most likely not appropriate in most of the mountainous areas that do not receive ample sunshine.

4.4.2. Solar thermal technology

With the national average sunlight hours of 6.8 h/day and solar insolation intensity of 4.7 kWh/m^2-day, there is a huge potential for solar thermal devices such as solar water heaters (SWH), solar dryers (SD), and solar cookers (SC). Presently SWH have been fully commercialized with a total installation of more than 100,000 panels in 80,000 households. SD and SC are still in the dissemination and the commercialization phase [43].

However, solar thermal devices are not suitable in those regions with long and harsh winters where the temperature falls below freezing. In addition, even ordinary solar water heaters cost $215 which is again costly for rural people [28]. In the case of solar cookers, frying is impossible, and the cooking time is longer and use is limited to times of sufficient sunshine. The lack of an energy storage system is another problem limiting their widespread promotion and dissemination in Nepal.

4.5. Wind energy

To date, little has been achieved in this sector. The Kagbeni wind power project was one of the biggest projects with installed capacity of 20 kW built in 1987 under the support of the Danish Government. Unfortunately, the wind power project could not sustain itself due to the lack of maintenance. The establishment of wind-solar hybrid systems of 400 W with 150 W solar power projects in six rural communities has been completed. More than 48 households and two secondary schools have directly benefitted from these micro-projects [44]. Although the government declared a plan to generate 20 MW electricity by wind energy in the Three Year Interim Plan (2007/08–2009/10), the lack of sufficient research data, and complicated geographical landscape of the country hindered its successful implementation. Also, the areas are very site specific without infrastructure and limited human settlement.

5. Opportunities

The United Nations Commission on Sustainable Development (CSD) identified access to sustainable energy services as an essential element of sustainable development. According to the Commission, "*to implement the goal accepted by the international community to halve the proportion of people living on less than $1 per day by 2015, access to affordable energy services is a prerequisite*" [45]. Poor people spend up to one-third of their income on energy mostly for preparing food. Women, in particular, devote a considerable amount of time in fetching firewood for cooking. In Nepal, on average, rural women spend 5 h per day collecting firewood [46]. On the top of this, use of wood fuel with improper cooking devices (e.g. traditional cooking stove) in poorly ventilated places leads to serious health implications specifically in women and children who spend

hours in smoke-laden indoor environments. There is a strong correlation among energy availability and education, health, urban migration, empowerment, local employment and income generation, and an overall improvement in the quality of life [46]. By realizing the link between energy availability and the quality of life, there are ample opportunities to divert the resources in line with millennium development goals to reduce poverty in developing countries through the implementation and promotion of RETs. Renewable energy has implicit potentials in contributing to improving the quality of life in rural areas through the promotion of trades and local industries, and employment opportunities at local level. Some specific opportunities associated with RETs in Nepal are:

- The rapid and unmanageable growth of major urban centers to some extent is linked to availability of various forms of energy. Migration toward urban areas provides people with a better quality of life through energy interventions. By providing energy services to smaller towns and rural areas, the urban migration could be controlled to a considerable extent in Nepal.
- Increasing the private sector participation in the renewable energy development and dissemination, and promoting competition in the service provision could help in enhancing the accessibility of technology to the consumers, reducing the cost and improving the quality of service.
- Widespread application of alternative energy technologies like biogas, micro/pico-hydro, solar, wind power and biofuels/bioenergy has tremendous potential in utilizing local resources and reducing GHG emission by developing countries; thereby creating possibilities of carbon trading in the global market. The revenue generated could be deployed for further research, development and dissemination of RETs in the developing countries.
- Neighboring countries—China and India are emerging global economic superpowers. China will become the number one energy consumer over the next quarter-century and its energy demand will increase by 75% between 2008 and 2035 [3]. India will also face increasing energy demands. Nepal with its enormous potential for hydropower generation could become a major energy exporter to its neighbors.
- Moreover, development of indigenous energy resources and the diversification of the energy supply can reduce long-term dependence on imported petroleum fuels and likely to lower national debts, thereby improving the national economy.

6. Challenges

The implementation of RETs that will support sustainable development still remains a big challenge to stakeholders involved in the promotion of renewable energy resources in developing countries [47]. Based on the analysis of the current situation of the country, some of the major barriers for the development and dissemination of RETs are:

Policy barrier: Despite the acceptance of the fact that energy is critical for development, energy has not received significant attention in policy debates. The government is directly and indirectly providing subsidy to import the fossil fuels and that has favored the increased use of imported fuels compared to pricy hydroelectricity. Also, the existing policy on micro-hydro development does not favor the poor and rural communities. Current subsidy policy is guided by 'bigger the better' and 'the more the merrier' philosophy. Although, smaller projects are usually more expensive and generate less revenue than the larger projects, project evaluation on the financial basis alone impedes the development of potential smaller micro-hydro system suitable for the small communities.

Lack of awareness and program in rural areas: Rural communities are unaware of both the benefits of the RETs and the adverse impact of existing practices on health, economy and the environment. Although, they often have access to renewable energy technologies, they lack the understanding of these technologies. Thus, they lack knowledge of successful replicable projects, government subsidies, potential financial partners, and the means for establishing renewable energy systems.

Lack of affordability: Even with the current level and modality of government subsidy, services from major RETs are unaffordable to the majority of the poor in rural areas. Comparatively higher initial costs of alternative energy options (e.g. micro-hydro and solar system), and lower affordability of low-income households are the major barriers for establishing such technologies in the rural areas. The lack of adequate other end-uses of the RETs in the rural areas is the main obstacle in promoting the economic viability of RETs in the regions; this is because the major use of the renewable energy is confined to just lighting (solar, biogas, micro-hydro) and cooking (biogas). The lack of integration of renewable energy to other end uses is a major challenge of RETs for better market penetration.

Financial barrier: Large-scale hydro projects require massive capital investment. The government does not have enough financial resources for investing in such projects. RETs like solar system, micro-hydro, and biogas are equally expensive for rural communities. Thus, rural people and local institutions cannot afford the capital costs of these technologies without adequate financial support from other organizations. All RETs are not yet commercial in Nepal. So, financial institutions are not readily motivated to invest in RETs because of the immature business models, market insecurity and implementation and usage risks.

Institutional barrier: AEPC, the single governmental agency for the promotion of RETs, is mainly focusing in the dissemination of the proven technologies through subsidy. However, the government has yet to establish institution with the sole responsibility of research and development of RETs that are most compatible for the nation's diverse socioeconomic and geophysical conditions.

Human resource barrier: Energy technologies have not received much coverage in most of the engineering and technical courses currently taught at universities and colleges in the country. There is no technical/vocational school that trains manpower in various aspects of renewable energy. At the local level, rural communities lack minimal level of technical knowledge to operate and maintain established renewable technologies.

Political barrier: Political instability in the country has greatly constrained the development of RETs. During the past three decades, Nepal has experienced three different political systems with more than a dozen of different governments. These frequent changes in the political system and subsequent changes in the governments have adversely affected long-term planning and policy formulation for the development of nation.

7. Recommendation

Because of the vast diversity in availability of resources, socioeconomic and geophysical conditions of the country, Nepal's energy needs should be guided by energy diversification since a single energy source is unlikely to fulfill the energy needs of the entire country. To satisfy the basic energy needs, the promotion of regional renewable sources like solar, wind, biomass and hydro, and a proper combination of these resources such as grid and non-grid solutions for electricity supply, liquid and gas fuels for cooking, and biomass wherever appropriate, should be adopted. Based on the analyses of the available resources and energy

demand, some of the recommendations for adopting RETs in Nepal are:

- *Decentralized energy resources*: Due to the rugged mountainous terrain and scattered nature of human settlements, the national grid extension to these areas is very difficult and uneconomical. Hence, decentralized energy sources could be the most cost effective alternative for such locality. Rural populations need to be encouraged to participate in the construction of integrated as well as isolated small-scale hydropower schemes for rural electrification. Also, end use diversification should be promoted to make such hydropower schemes economically viable.
- *Energy cooperatives*: The implementation of a cooperative concept could be an excellent option for Nepal for developing and implementing renewable energy resources in rural parts. Financial, technical and legal supports could certainly facilitate the development of RETs. Also, the formulation of a cooperative model provides the effective platform for the mobilization of local resources in the development and dissemination of RETs.
- *Sustainable management of community forestry*: For cooking in rural areas, biomass is likely to remain as the main fuel source for a foreseeable future. One option that could be viable is the sustainable management of community forestry for bioenergy purposes. The formulation of cooperative group from community forest user groups and the sustainable collection and utilization of fuel wood for charcoal production can provide better quality energy sources with a higher energy density, better efficiency and lower emission of indoor air pollutants. If properly managed, community forests will generate additional revenue which could ultimately benefit the user groups. The utilization of charcoal in improved cooking stoves will reduce the emission of indoor air pollutants and will minimize the work load on women collecting fuel wood.
- *Bio-briquetting*: Bio-briquetting of abundant forest and crop residues could be a viable option. Bio-briquettes are clean and, nearly smokeless fuel sources with higher energy density (heating value of bio-briquette produced from Banmara (Crofton weed, *Upatorium adenophorum.* L.) is about 17.3 MJ/kg [32]), and are ideal for both cooking and space heating. Moreover, a wide range of otherwise unusable bio-materials can be used for bio-briquette production. Because of the effective use of forest and agricultural residues, this technology could significantly reduce the fuel wood consumption, deforestation, and indoor air pollution.
- *Biogas technology*: In the case of biogas, research on low-cost and cold climate biogas plants is needed to make it affordable to poor rural people and accessible in cold climate mountainous regions. Furthermore, the biogas program should be expanded to utilize different biodegradable wastes like kitchen wastes, municipal and industrial organic wastes as potential feedstocks. This will require modification in the existing digester design and operation.
- *Hydroelectricity*: For hydroelectricity development, priority should be given to develop small and medium/micro hydropower plants to meet the domestic demands. In such projects preference should be given to mobilize local financial resources by encouraging the private sector to invest. For large multipurpose hydroelectricity projects, negotiation with lower riparian countries like India and Bangladesh should be carried out to establish a mutually beneficial treaty like the Columbian Treaty between USA and Canada (USA had to pay $64.4 million to Canada for flood protection [47]). Such treaty will provide both investment requirements for mega projects and create markets for the export of electricity. Also without agreement between co-riparian countries for sharing benefits, the World Bank and other donor agencies would not be interested to invest in the project [48]. Thus, for the development of large hydroelectricity projects in Nepal, a good understanding between Nepal and India is crucial both to meet the financial requirement and to market the electricity.
- *Fossil fuel substitution*: Agro-based industries such as sugar, jute and paper should utilize the wastes/residues for sustainable renewable energy production. To realize the maximum potential of hydropower to replace fossil fuels in the domestic, transportation, and industrial sectors, NEA should produce and provide more electricity at favorable tariffs. This will motivate the users to use electricity in place of imported petroleum-based fuels, which will not only generate additional revenue for NEA, but also utilize 'wasted' off-peak electricity. The imposition of environmental taxes and regulations to fossil-derived energy users may encourage industries and other consumers to shift to renewable energies.
- *Biofuels*: Nepal has limited arable land which has been aggressively utilized for food, feed and other commercial crop cultivation. It is therefore hard to allocate any land for the large-scale cultivation of energy crops such as *Jatropha* as practiced in neighboring countries; China and India. However, local level collection, processing and use of liquid biofuel feedstocks from indigenous trees and oil bearing non-food plant resources must be promoted, wherever feasible. Such biofuels could serve as the best alternative to costly kerosene and diesel fuels which the rural people are using for lighting and grain milling, respectively.
- *Microfinancing*: Even with government subsidies, especially in remote areas, people cannot afford to cover the capital cost of installing RETs like solar system, biogas, micro-hydro and wind power. In order to improve everyone's access to RETs, provision for financing services (soft loans) should be made available. To fulfill the credit requirement of the rural people with fewer hassles, micro finance institutions should be established in target areas. Such institutions being more close to the borrower will reduce the time needed for debt management. Also, poor people who usually hesitate to deal with the big financial institution may find it more comfortable to deal with micro finance institutions like cooperatives [46].
- *Awareness program*: To develop RETs as a viable and sustainable option for developing countries like Nepal, it is important to educate the people about the potential economic, health and environmental merits of renewable energy. There is a need to develop programs that bring awareness and disseminate knowledge to a wide audience through a variety of mass media and multi-stakeholder dialogues.

8. Summary

Nepal has a vast number of natural energy resources, but only small fraction (renewable resources contribute to less than 1.0% of total energy consumption) has been harnessed due to geophysical, technical, economical and political reasons. The majority of the population in rural areas relies on traditional biomass resources for energy; whereas in cities, they are forced to use expensive imported fossil fuels for fulfilling their energy needs. The excessive but poor usage of the biomass and increasing use of fossil-based energy sources have promoted negative impacts on public health, the environment and the national economy. Also, under the current state of technologies, infrastructures and policy, the Nepalese people will continue to rely on traditional biomass resources and imported fossil fuels for many years to come. Thus, for developing countries like Nepal, the use of RETs has a large potential, both in terms of available renewable resources and providing clean and reliable energy, to curtail the import of costly fossil fuels, create employment opportunities, preserve the local environment, and improve the quality of life. The realization of the aforesaid poten-

tials, however, requires a more systematic and comprehensive study supported by research and development. Moreover, larger quantities and better qualities of energy resources are prerequisites for meeting all of the millennium development goals because of its inherent links to poverty alleviation, education, gender equality, health, and the protection of the environment. Considering the diversity in both available resources and socioeconomic and geophysical conditions, energy policy should pay due care on the proper hybridization of different energy options to meet both the affordability and acceptability of the local people.

Acknowledgments

The authors are grateful to the AEPC, Ministry of Environment, Government of Nepal for providing us with valuable data. Personally, we are thankful to Anil Nath Shrestha, Engineer, Renewable Energy Development Program, and Narayan Adhikari, Engineer, AEPC, for sharing important information with us. The authors would like to thank Devin Takara, University of Hawai'i at Manoa for internal review of the manuscript. Further, this paper is largely based on the various published papers and project reports as mentioned in references. Authors of these reference materials are gratefully acknowledged.

References

[1] ADB. Asian Development Bank and Nepal – fact sheet. Online information http://www.adb.org/Documents/Fact_Sheets/NEP.pdf [retrieved 10.10.2010].
[2] World Bank. World Development Indicators database. http://siteresources.worldbank.org/DATASTATISTICS/Resources/GDP.pdf [retrieved 15.12.2010].
[3] IEA, International Energy Association. Key world energy statistics 2010. http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf [retrieved 10.09.2010].
[4] MoF, Ministry of Finance 2009. http://www.mof.gov.np/publication/budget/2009/pdf/chapter10.pdf [retrieved 15.09.2010].
[5] MoF, Ministry of Finance. Economic Survey 2006/2007. http://www.mof.gov.np/publication/budget/2007/surveyeng.php [retrieved 15.09.2010].
[6] Shrestha HM. Cadastre of hydropower resources. PhD Thesis, Moscow Power Institute, Moscow, USSR; 1966.
[7] NEA, Nepal Electricity Authority. Fiscal year 2007/2008—a year in review 2008. NEA; 2009.
[8] Bhattarai TN. Efficient biomass fuel combustion for economy, health and environment. In: Proceedings of international conference on renewable energy technology for rural development. 2003. p. 405–11.
[9] Shrestha JN, Bajracharya TR, Shakya SR, Giri B. Renewable energy in Nepal—progress at a Glance from 1998 to 2003. In: Proceedings of international conference on renewable energy technology for rural development. 2003. p. 1–10.
[10] WECS, Water and Energy Commission Secretariat. Energy sector synopsis report 2010. Kathmandu, Nepal; 2010.
[11] WECS, Water and Energy Commission Secretariat. Energy sector synopsis report 2006. Kathmandu, Nepal; 2006.
[12] SNV/N. Netherland Development Organization-Nepal. Programme support to Nepal's renewable energy sector, introduction and analysis. SNV/Nepal, Kathmandu, 2001.
[13] Metz JJ. Forest-product use in upland Nepal. Georgia Rev 1990;80:279–87.
[14] Sharma M, Bhattacharya SC. A study of biomass as a source of energy: Nepal. Energy Sustain Dev 1997;3:40–5.
[15] Shrestha BB. Fuel wood harvest, management and regeneration of two community forests in Central Nepal. Himal J Sci 2005;3:75–80.
[16] ADB-ICIMOD, Asian Development Bank-International Centre for Integrated Mountain Development. Environment assessment of Nepal: emerging issues and challenges. Kathmandu, Nepal: ADB-ICIMOD; 2006.
[17] APO, Asian Productivity Organization. Solid waste management: issues and challenges in Asia. APO; 2007.
[18] SWMRMC, Solid Waste Management and Resource Mobilization Centre. Diagnostic report on the state of solid-waste management in the municipalities of Nepal. Lalitpur, Nepal: SWMRMC; 2004.
[19] Shrestha JN, Kojima T. Non-CO_2 emitting renewable energy sources in Nepal: problems and prospects. Energy Convers Mgmt 1997;38:S685–9.
[20] Shrestha JN. Solar radiation in Nepal: its implications in telecommunication services. In: Proceedings of first national conference in renewable energy technology for rural development. 2006.
[21] IEA, International Energy Association. Key world energy statistics 2008. IEA; 2008.
[22] Shrestha JN. Energy for development in the perspective of Nepal. In: Proceedings of two days national conference in decentralized rural energy development in Nepal: challenges, opportunities and strategic options. 2009. p. 21–6.
[23] WECS, Water and Energy Commission Secretariat. Perspective energy plan, energy synopsis report supporting document. Kathmandu: WECS; 1994. p. 12–13.
[24] BSP, Biogas support programme. BSP year book 2009. BSP; 2009.
[25] CES, Centre for Energy Studies. The feasibility studies of geothermal energy application in Nepal. CES; 2001.
[26] WECS, Water and Energy Commission Secretariat. Energy Synopsis Report-Nepal, 1994/95. Kathmandu: WECS; 1996.
[27] Gongal RN, Shrestha S. A case study of biogas program in Nepal. In: Rijal K, editor. Renewable energy technologies: a brighter future. Kathmandu, Nepal: International Centre for Integrated Mountain Development; 1998. p. 157–69.
[28] REDP, Rural Energy Development Programme. Rural energy technologies. http://www.redp.org.np/phase2/rural.php [retrieved 06.09.2010].
[29] WHO, World Health Organization. Indoor air pollution: National burden of disease estimates. Geneva, Switzerland: WHO Press; 2007 [retrieved 15.09.2010] http://www.who.int/indoorair/publications/indoor_air_national_burden_estimate_revised.pdf.
[30] Bajracharya A. Jaibik Urja Sahayog Karyakram: Yek Janakari. Sabaiko Lagi Urja Aviyan Urja Nepal 2010;2:13–6.
[31] Bajracharya K, Gongal RN. A case study of the improved cooking stove programme. In: Rijal K, editor. Renewable energy technologies: a brighter future. Kathmandu, Nepal: International Centre for Integrated Mountain Development; 1998. p. 171–80.
[32] Singh RM, Heejoon K. Biobriquettes—an alternative to fuel wood and coal. In: Proceedings of international conference on renewable energy technology for rural development. 2009. p. 150–2.
[33] Practical Action Nepal. Inventory of innovative indoor smoke alleviating technologies in Nepal; March 2007. http://www.indoorair.org.np/Inventory%20of%20innovating%20Smoke%20alleviating%20products.pdf [retrieved 15.11.2010].
[34] Dhakal NR, Dhakal N. An overview of biofuel programme. In: Proceedings of international conference on renewable energy technology for sustainable development. 2009. p. 112–8.
[35] Bhattarai K. Nepalma Biodiesel ko Sambhabana ra Aabasyakata. Sabaiko Lagi Urja Aviyan Urja Nepal 2010;2:9–12.
[36] Gerbens-Leenesa W, Hoekstraa AY, Van der Meerb TH. The water footprint of bioenergy. Proc Natl Acad Sci USA 2009;106(25):10219–23.
[37] SNV/WWF, Netherland Development Organization Nepal and World Wildlife Fund. Developing sustainable pro-poor biofuels in the Mekong Region and Nepal; 2009. http://www.snvworld.org/en/ourwork/Documents/ Developing_Sustainable_Pro-Poor_Biofuels.pdf.
[38] http://www.nepalitimes.com.np [retrieved 31.10.2008].
[39] Singh SC, Singh N, editors. Non-conventional sources of vegetable oil [Bangladesh, Nepal and Pakistan]. Kathmandu: Nepal Lithographing Co.; 1991.
[40] Shrestha GL. Traditional oil extracting technology in Nepal with special reference to Jumla. In: Proceedings of national seminar on plant oil energy in Nepal. 1996. p. 66–9.
[41] CRT/N, Centre for Rural Technology, Nepal. Internal Database; 2009.
[42] Draft report on status of photovoltaic in Nepal; 2010.
[43] Shrestha JN. Application of building integrated photovoltaic electric system: it's contribution in reduction of load shedding hours in Nepal. J Inst Eng 2009;7:11–7.
[44] AEPC, Alternative Energy Promotion Centre. Overview of wind energy—internal database; 2010.
[45] GREENPEACE/ITDG, Sustainable energy for poverty reduction: an action plan; 2002. http://practicalaction.org/docs/advocacy/itdg-greenpeace-study.pdf [retrieved 15.09.2010].
[46] Nepal G, Amatya VB. Understanding rural energy programme and poverty reduction linkage: an empirical study of Nepal. Energy Sector Assistance Programme. Lalitpur, Nepal: Alternative Energy Promotion Centre; 2006.
[47] Thapa AB. Karnali downstream benefit. Water Energy Comm Secretariat Bull 1997;8:6–10.
[48] Sharma CK. Water and energy resources of the Himalayan block (Pakistan, Nepal, Bhutan, Bangladesh and India). Calcutta: N.P. Works Pvt. Limited; 1983.